



C. David Whitefield, P.E.
Principal Applications Engineer
Bently Nevada Corporation
e-mail: dave.whitefield@bently.com

Clean Up Your Oil – *Revisited*

Editor's note: This article is an update to an article previously published in the Fourth Quarter 1999 ORBIT. The ISO section has been updated to conform to the latest ISO specification for fluid cleanliness, ISO 4406:1999. Please see the sidebar for additional details on the changes arising from ISO 4406:1999.

Contaminated oil kills machines. Clean oil is one of the most important factors affecting the service life of the lubricated components of all machinery.¹ In hydraulic systems, clean fluid is absolutely essential for successful long-term operation. Although machines equipped with rolling element bearings are especially sensitive to particulate contamination, machines using fluid-film bearings are not immune to such damage. Many sources cite dramatic improvements in expected machine life resulting from even modest improvements in lubricant cleanliness.

This all sounds reasonable, and smacks of common sense. However, closer scrutiny reveals a few important questions:

- ✖ How is oil cleanliness quantified?
- ✖ How clean is "new" oil?
- ✖ How clean does your oil need to be?
- ✖ What improvements in machine life can you expect from cleaning up your oil?
- ✖ What about other types of contamination?
- ✖ What steps can you take to clean up your oil?

Let's look at these issues one at a time ...

How Is Oil Cleanliness Quantified?

ISO 4406:1999 establishes the relationship between particle counts and cleanliness in hydraulic fluids (common practice has extended the application of this standard to lubricants as well). This international standard uses a code system to

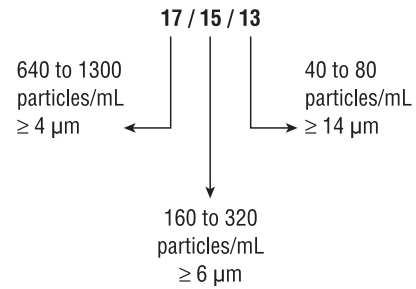
¹ For the purposes of this article, and in keeping with common industry practice, the terms "clean" and "cleanliness" refer to the amount and size of particulate contamination in a lubricating or hydraulic fluid.

ISO 4406:1999 FLUID CLEANLINESS CODES

NUMBER OF PARTICLES PER 1 mL OF FLUID		
ISO CODE	MINIMUM	MAXIMUM
1	0.01	0.02
2	0.02	0.04
3	0.04	0.08
4	0.08	0.16
5	0.16	0.32
6	0.32	0.64
7	0.64	1.3
8	1.3	2.5
9	2.5	5.0
10	5.0	10.0
11	10.0	20.0
12	20.0	40.0
13	40.0	80.0
14	80.0	160.0
15	160	320
16	320	640
17	640	1300
18	1300	2500
19	2500	5000
20	5000	10000
21	10000	20000
22	20000	40000
23	40000	80000
24	80000	160000
25	160000	320000
26	320000	640000
27	640000	1300000
28	1300000	2500000

TABLE 1

ISO CODE EXAMPLE



quantify contaminant levels by particle size in micrometers (μm). Using ISO 4406:1999, a machine owner/operator can set simple limits for excessive contamination levels, based on quantifiable cleanliness measurements.

Table 1 illustrates the ISO 4406:1999 cleanliness codes.² This standard allows you to quantify current particulate cleanliness levels and set targets for cleanup. The standard provides a 3-part code to represent the number of particles per milliliter (mL) of fluid greater than or equal to 4 μm, 6 μm, and 14 μm, respectively. For example, referring to Table 1, an ISO code of **17/15/13** would indicate 640 to 1300 particles/mL greater than or equal to 4 μm, 160 to 320 particles/mL greater than or equal to 6 μm, and 40 to 80 particles/mL greater than or equal to 14 μm are present in the lubricant. Notice each step in the ISO code represents either double or half the particle count relative to an adjacent code. It is important to note that the "/" character in the written form of the code is merely a separator, and does not signify a ratio of the scale numbers.

How Clean Is "New" Oil?

Studies of "new" turbine oils, crankcase oils, hydraulic fluids and bearing oils delivered to customers indicate varying degrees of cleanliness. Drum-delivered products were generally found to be cleaner than bulk-delivered products. Improper storage procedures can contribute additional contamination to new oil. Poor handling practices are another source of new oil contamination. (Do you know what types of containers are used in your plant for transporting and adding makeup oil? Are they as clean as you want your oil to be?) After implementing cleanup programs, many users discover that the dirtiest oil in their plant is the incoming "new" oil.

² The ISO standard calls the codes "scale numbers." You may also find them referred to as "range numbers" and represented as $R_4/R_6/R_{14}$.

Therefore, it is clear that proper filtering of new oil during or before filling is a prudent and highly desirable practice in order to extend machine life.

How Clean Does Your Oil Need to Be?

Each machine class should be evaluated for cleanliness levels appropriate to the application. In general, machines with tight clearances and/or anti-friction (rolling element) bearings benefit greatly from very clean oil. Turbine electro-hydraulic control (EHC) systems and many aeroderivative gas turbines are examples of industrial machines that require extremely clean oil for proper performance and long life. Filter systems rated to remove particles as small as 3 µm to 7 µm are commonly used in such applications. Hydraulic systems targets should also be adjusted to cleaner levels due to higher system operating pressures.

Table 2 presents some typical lubricating oil base-cleanliness targets for common machines and machine elements. Like most guidelines, these targets are suggested as starting points. You will probably make adjustments to these levels as you learn how your machines respond to cleaner lubricants.

What Improvements in Machine Life Can You Expect From Cleaning Up Your Oil?

While it may feel good to know you have clean oil in your machines, how good can you afford to feel? The answer to this question depends to some degree on the specific machine application. However, studies performed across many industries all show dramatic extensions in expected machinery life by improving lubricant cleanliness. In one example, the reduction of particles larger than 10 µm from 1000/mL to 100/mL resulted in a 5-fold increase in machine life ... an attractive return on your cleanup investment. An additional benefit of cleaner oil is a lower noise-floor for wear-particle detection measurements. It's much easier to detect subtle changes in the amount of wear debris in a clean system than it is in a dirty one.

Society of Automotive Engineers (SAE) studies have shown engine wear reductions of 50% when filtering crankcase oil to 30 µm, and 70% when filtering to 15 µm, as compared with filtering to 40 µm.

TYPICAL BASE-CLEANLINESS TARGETS

MACHINE / ELEMENT	ISO TARGET
Roller bearing	16/14/12
Journal bearing	17/15/12
Industrial gearbox	17/15/12
Mobile gearbox	17/16/13
Diesel engine	17/16/13
Steam turbine	18/15/12
Paper machine	19/16/13

TABLE 2

By implementing some of the measures outlined in this article, you will soon be able to document your own success stories.

What About Other Types of Contamination?

As destructive as particulate contamination can be, there are other contaminants that also contribute to oil degradation and premature machine wear. A short list of “non-particulate” contaminants includes water, coolants, fuels, and process fluids. The most common of these is water, which by itself is a significant factor in lubricant degradation (Figure 6). When combined with iron or copper particles, water becomes even more powerful in attacking lubricant base stocks and additives. The adverse effects of water in oil include:

- ✖ Lubricant breakdown, through oxidation and additive precipitation.
- ✖ Changes in viscosity, affecting the ability of a lubricant to maintain the film thickness necessary to protect the lubricated surfaces.
- ✖ Corrosion.
- ✖ Accelerated fatigue of lubricated surfaces.

Even very small amounts of water can be harmful in machines equipped with rolling element bearings. Typical life reduction of rolling element bearings caused by various concentrations of water in oil is depicted in Figure 1.

EFFECT OF WATER ON ROLLING ELEMENT BEARING LIFE

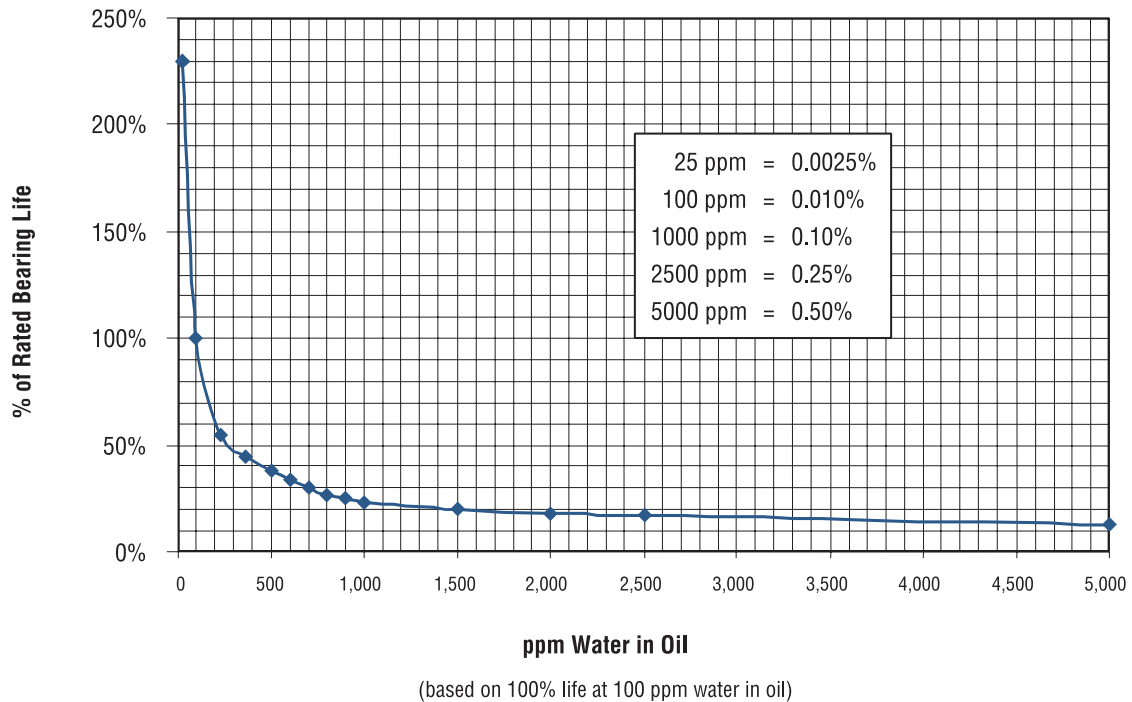


FIGURE 1

Lubricant film thickness in fluid-film journal bearings is substantially larger than found in rolling element bearings, and hydrodynamic pressures are typically lower. However, the babbitt material in these bearings, being composed primarily of lead and tin, is susceptible to oxidation damage from water and oxygen. Water can also reduce the load-carrying capacity of a fluid-film bearing lubricant sufficiently to cause journal-to-bearing contact (wiping). The reduction in film thickness also exacerbates the sensitivity of fluid-film bearings to particulate contaminants.

What Steps Can You Take to Clean Up Your Oil?

Let's say you are now convinced that cleanup is the way to go, but do you know how to get there? Filtration, storage, and handling procedures are the key areas in which to concentrate your energies. The important elements of a successful campaign to clean up your oils are:

- ✖ Measure and evaluate current cleanliness levels to establish baselines for comparison.
- ✖ Examine and evaluate your current storage and handling practices.
- ✖ Set cleanliness targets based on your goals for longer machine life and/or reduced maintenance and downtime costs.
- ✖ Evaluate, select, and implement the improvements in filtration, storage, and handling procedures required to achieve your goals.
- ✖ Measure and trend your progress. (Don't be afraid to adjust your procedures as needed to meet your targets.)
- ✖ Document the impact of your investment on availability, maintenance expense, and machine life.

With these elements delineated, some of the practical aspects of improving your filtration, storage, and handling procedures can be addressed.

Improving Your Filtration, Storage, and Handling Procedures

Many improvements to your filtration, storage, and handling procedures can be made with minimal cost. A little time spent simply reviewing your current procedures can be revealing (and in some cases, even **shocking**). Figures 2 through 4 illustrate a few common problems likely to be encountered in many operations. During the evaluation phase it is important to identify contamination **sources** as well as their levels. Contamination sources may include:

- ❖ **Contaminated new oil.** As previously mentioned, new oil is often not as clean as you might think; sometimes it becomes contaminated during transportation, storage, or handling.
- ❖ **Built-in contamination.** Machine components can become contaminated from handling practices encountered during overhauls or rebuilding processes. It is important to review shop procedures relating to cleanliness of internal wetted parts, hoses, and lubricant piping.
- ❖ **Ingested contamination.** Unfiltered sump vents and faulty seals are common problems that can result in contaminants (including water or particulates) entering the lube system from the outside environment. Minor modifications to vent systems can reap rewards in this area.
- ❖ **Internally generated contamination.** Recirculating wear particles through machine components can create a self-fulfilling prophecy of machine destruction. Normal full-flow filtering removes some, but not all, wear particles; and in fact, many full-flow filtration systems are only effective at removing particles larger than 40 μm . Concentrating on the hardest and most abrasive particles is an effective strategy for this category of contaminants.

Once the contamination sources are identified, you can concentrate on the areas most likely to generate your target cleanliness levels.

HOW DOES DIRT GET IN?

POOR FILTERING PRACTICES

– *filler neck screen punched out.*



FIGURE 2

POOR STORAGE PRACTICES

– *loose bung (drum cap).*



FIGURE 3

POOR HANDLING PRACTICES

– *dirty fill pump.*



FIGURE 4

Portable filter cart.



FIGURE 5

Filtration

Off-line recirculating (“kidney loop”) filtration systems can be very effective in achieving and maintaining your cleanliness targets. In some cases, a permanent installation is called for, with continuous sidestream (“bypass”) filtering. For less critical applications, where sump volumes are usually smaller, the job can often be handled with a cart-mounted portable filtration system (Figure 5). These portable systems can be used at scheduled intervals, or in response to increasing contamination trends in your oil analysis data. Portable systems can also be used for pre-filtering new oil before or during system charging. Cartridge-type filters are common on this type of equipment, so you can easily change to the appropriate filter element for the specific cleanliness target of each machine or machine class being serviced. Since cross-contamination is a possibility with portable systems, filter changes and adequate flushing are essential before use with a different lubricant. Maintaining separate systems for each lubricant being filtered is a way to avoid this potential problem.

Storage and Handling

Improvements to storage and handling procedures can often be implemented at low cost, relative to the benefits. Controlling temperature over a relatively narrow range is important for proper drum storage. Drums “breathe” as the internal pressure increases and decreases with temperature

variations, causing moisture and other contaminants to get pulled into the drum when the internal pressure decreases. In most climates, this problem must be addressed by storing drums in enclosed, temperature-controlled storage facilities. Shielding storage containers from dirt and moisture are other obvious measures that will keep your new oil in good condition. Be as careful with pumps and transfer containers as you are with your storage containers. This will minimize the chances of cross-contamination with other lubricants or the introduction of contaminants into machines when topping or filling.

Water Removal

Because the sources of water contamination are so numerous and ubiquitous, eliminating all sources of moisture ingestion can be very difficult. Removing water from oil can also be a challenging task, but there are several methods available. Each method has advantages and disadvantages, so each must be carefully evaluated for the particular application. Some of the common methods for removing water from oil, along with their tradeoffs, include:

- ❖ **Settling/Evaporation**
 - ⌚ Natural – gravity acts on the water to separate it from the oil and water escapes from the fluid via natural evaporation.
 - ⌚ Inexpensive.
 - ⌚ Least effective of known methods.
 - ⌚ Requires properly designed reservoir.
 - ⌚ Removes only free water.
- ❖ **Centrifuging (Centrifugal Separation)**
 - ⌚ Removes only free water to about 20 ppm by weight above saturation point.
 - ⌚ Does not remove entrained gases.
 - ⌚ Tends to increase emulsified water content.
 - ⌚ Removes dirt and other solids.
 - ⌚ Since this is a physical separation method, there is some potential for additive removal.
- ❖ **Coalescing Filters/Screens**
 - ⌚ Removes only free water.
 - ⌚ Uses a coalescing cartridge filter to separate the water from the oil.

- ☞ Since this is a physical separation method, there is some potential for additive removal.
 - ☞ Only effective for a narrow viscosity range and a narrow specific gravity range.
 - ☞ Some manufacturers claim “No removal of additives.”
- ✗ **Filter/Dryers**
- ☞ Cartridge-type filters that use super absorbent materials to soak up water as the wet lubricant passes through.
 - ☞ Does not remove dissolved water.
- ✗ **Vacuum Treating (Vacuum Dehydrating)**
- ☞ Uses simultaneous exposure of the wet lubricant to heat and vacuum to separate the water.
 - ☞ Because it is a chemical separation, it tends not to remove additives from the lubricant.
 - ☞ Capable of removing dissolved, emulsified, and free water.
 - ☞ When combined with effective filtration media, capable of being a highly effective lubricant purification system.
- ✗ **Gas Sparging/Air Stripping**
- ☞ Operates on the chemical separation principle of air stripping.
 - ☞ Removes dissolved, emulsified, and free water.
 - ☞ Does not remove additives.
 - ☞ Can use nitrogen or air.

Purchasing Clean Oil

An additional cleanup step, often overlooked, is to specify the cleanliness levels of the lubricants you purchase. You may pay a little more initially, but the savings in machine availability,

Visual effects of water in oil.

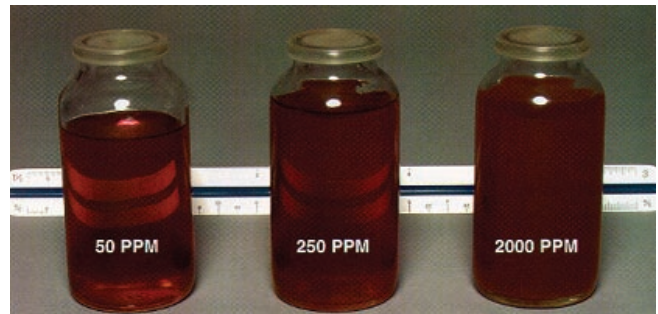


FIGURE 6

filtration costs, and machine life extension often more than offset the additional cost. If you choose this route, be sure to test the incoming oil to verify you are getting what you pay for.

Conclusion

It's best not to take administration of your oils lightly. Attention to detail is paramount in achieving cleanliness levels that yield significant improvements in machine life and availability. When it comes to machine life, lubricant cleanup has proven to be one of the simpler and more cost-effective methods of achieving measurable improvement. Don't wait for contaminants to destroy your machines. **Clean up your oil and keep it clean!** ORBIT

References:

1. Toms, Larry A., *Machinery Oil Analysis, Second Edition*, Coastal Skills Training, Virginia Beach, Virginia.
2. Fitch, J.C., *Oil Analysis Course Manual*, Noria Corporation, Tulsa, Oklahoma.
3. *A Guide to Standards for Contamination Specifications in Liquids*, Pacific Scientific Instruments, HIAC Royco Division.
4. *ISO 4406:1999*, International Standards Organization.
5. *Industrial Oils*, Chevron USA, Incorporated.
6. *The Handbook of Hydraulic Filtration*, Parker Hannifin Corporation, Parker Filtration Division.
7. *Machine Design*, "How Dirt and Water Affect Bearing Life," Timken Bearing Company.

Frequently Asked Questions (FAQs)

Concerning ISO 4406:1999

Hydraulic Fluid Power Solid Contaminations Code

What has changed as a result of ISO 4406:1999 and ISO 11171?

- The way particle size is specified – the new standard moves the measurement reference in order to correct for inaccurate calibration assumptions in the previous standard.
- Particle size was previously only measured in 2 dimensions, while the new standards account for particle size in 3 dimensions. The calibration standard for automatic (optical) particle counting equipment had to be modified to accommodate this change. A new calibration standard, ISO 11171, Automatic Particle Counter calibration procedures, replaced the old ISO 4402 standard. ISO 11171 specifies ISO Medium Test Dust (ISO MTD) as the Standard Reference Material (SRM), replacing the previously used material, AC Fine Test Dust (ACFTD). The ISO MTD material is National Institute of Standards and Technology (NIST) traceable, a characteristic ACFTD never enjoyed. The net result of these changes is a calibration procedure that provides more consistent and verifiable particle counting results in different labs around the world.

What hasn't changed as a result of the new standard?

- The amount and size of particulate contamination in your system.
- The functioning of your filtration and contaminant removal systems.
- The importance of proactive contamination measurement and control in extending the life of your machines.

How do the new and old measurement references compare?

- The size classification of the particles has changed. This is illustrated by the following table:

[Note: The particles didn't actually change size; the reference we use to measure them was more accurately defined, resulting in the new numbers.]

PARTICLE SIZE CLASSIFICATION COMPARISON	
ISO 4402 (ACFTD)	ISO 11171 (ISO MTD)
< 1.0 µ	4.0 µ
1.0 µ	4.2 µ
2 µ	4.6 µ
3 µ	5.1 µ
5 µ	6.4 µ
10 µ	9.8 µ
15 µ	13.6 µ
20 µ	17.5 µ
25 µ	21.2 µ
Old Size (ISO 4402)	New Size (ISO 11171)

TABLE 1

Do these changes affect how I specify my cleanliness targets?

- No, your targets remain the same, unless you were using the old 2-character code ($\geq 5 \mu$ and $\geq 15 \mu$). In that case, you would use the old codes for the $\geq 6 \mu$ and $\geq 14 \mu$ ranges, and select an additional code for the $\geq 4 \mu$ range, typically 1 or 2 scale numbers higher than the $\geq 6 \mu$ scale number. Of course, if you decide to set tighter targets, you are certainly free to do so.

Do all oil analysis labs use the new standards?

- No, this change is still "filtering" its way through the industry. However, the consensus is that those labs that are focused on high standards for quality and consistency of results are moving the fastest to embrace the new standards. *[Editor's Note: National Tribology Services (NTS), the lubricant condition analysis lab with which Bently Nevada has a cooperative agreement, has adopted this new ISO standard.]* ORBIT